TIME AND FREQUENCY ACTIVITIES AT NIST

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Abstract

The mission, organization, and activities of the Time and Frequency Division of the National Institute of Standards and Technology are described. Topics covered include frequency standards, time scales, time transfer, optical frequency standards, spectral-purity measurements, synchronization for telecommunications, and time and frequency broadcast services.

INTRODUCTION

During the last decade, two other reports on the activities of the Time and Frequency Division of NIST[1,2] have been presented at PTTI Meetings. This paper provides a very general update to that material with specific mention of some of our most recent activities. This introduction briefly describes the mission and organization of the Division, while the remaining sections offer a bit more information on activities of the Division.

The mission of the Time and Frequency Division is to support U.S. industry and science through provision of measurement services and research in time and frequency and related technology. To fulfill this mission the Division engages in:

- the development and operation of standards of time and frequency and coordination of them with other world standards;
- the development of optical frequency standards supporting wavelength and length metrology;
- the provision of time and frequency services to the United States; and
- basic and applied research in support of future standards, dissemination services, and measurement methods.

The work supporting length metrology derives from the definitional dependence of the meter on the second. This work contributes to a larger program in the Precision Engineering Division of NIST's Manufacturing Engineering Laboratory, which has primary responsibility for length and its dissemination.

The Division is organized into eight technical Groups: Time and Frequency Services, Time Scale & Coordination, Cesium Standards, Ion Storage, Spectral Purity Measurements, Laser Spectroscopy, Optical Frequency Measurements, and Network Timing. The Groups are necessarily small, and the Group Leaders are, thus, able to function primarily as technical leaders within their areas. The unifying theme of time and frequency measurement runs through each of these Groups, bringing strong interaction among the Groups.

NEW FREQUENCY STANDARDS

The accuracy of NIST's time scale is derived from primary frequency standards which provide the practical realization of the definition of the second. To meet advancing needs, the Division has constructed a new frequency standard, NIST-7, which went into operation in early 1993. This atomic-beam standard[3,4] is based on optical pumping (using diode lasers) rather than the traditional magnetic methods used for state selection and detection. The current uncertainty for this standard is 5×10^{-15}, but further improvements in evaluation methods should allow for improvement perhaps to 1 or 2×10^{-15}. The Division is constructing a new cesium-fountain frequency standard[5], which should be in operation within the next year. This work is a collaboration with the Atomic Physics Division of the Physics Laboratory at NIST, the Politecnico di Torino, and the Istituto Elettrotecnico Nazionale Galileo Ferraris. Looking toward still higher accuracy, the Division is studying standards based on trapped, laser-cooled ions[6,7]. Ion standards offer promise of accuracy improvements of many orders of magnitude. While the ion studies continue to involve demonstrations of prototype clocks, the work is treated as basic research, providing the knowledge base for future standards.

IMPROVED TIME SCALES

The NIST time scale is the stable clock system which provides accurate signals for services and applications and which serves as a reference for research on new standards and measurement methods. The reliability and stability of this time scale is based on the use of an ensemble of frequency standards combined under the control of a computer-implemented algorithm. The key internal time scale used by NIST is called AT1. Recent improvements to the scale[8] involve the addition of new commercial hydrogen masers and cesium-beam standards and the development of new reset procedures in the AT1 algorithm. The drift rate of the scale has been reduced from 1×10^{-16}/day to 3×10^{-17}/day. The random fluctuations of AT1 were also reduced by a factor of 2 to 2×10^{-15} at 100 days. Further improvements are expected as two additional hydrogen masers are added to the scale. Improvements are also being made in the electronic systems which read the clock outputs. All of these improvements are critical to the successful evaluation and use of the next generations of primary frequency standards now being developed by the Division.

IMPROVED METHODS OF TIME TRANSFER

Since the world operates on a unified time system, Coordinated Universal Time (UTC), highly accurate time transfer (to coordinate time internationally) is a critical ingredient in the operation of time scales and primary frequency standards. The Division is working to further improve the GPS common-view time transfer method, which is the key method now used for international time coordination.[9] The Division is also working with others (including USNO) to improve the two-way time transfer method. While the simplicity and reliability of common-view time transfer makes it the current method of choice, the two-way method offers good potential for improved performance. A two-way link between North America and Europe has been studied, and another two-way link to the Pacific region is under development. Recent NIST work has focussed on errors in the earth stations.[10]

IMPROVED OPTICAL FREQUENCY STANDARDS

The Division is also engaged in developing improved optical frequency measurements important for primary frequency standards, secondary wavelength standards based on atomic and molecular transitions, advanced optical communication, analytical instrumentation, and length measurement. The most obvious interest is in the development of future primary frequency standards using optical transitions, since, in general, higher frequency transitions yield a better fractional-frequency uncertainty. Another area of effort is on diode lasers, which can have very high spectral purity, tunability, simplicity, and low cost.[11] The approach taken in this work is to prove concepts through demonstration of working systems. The Division also develops and characterizes accurate optical frequency and wavelength references such as the carbon dioxide laser[12] and the calcium-stabilized diode laser.[13] Such frequency references serve as standards in making accurate spectroscopic measurements in industrial and scientific programs. The program has recently been expanded to include a responsibility for the development of advanced optical-frequency standards to support improved length measurement and standards.

IMPROVED SPECTRAL-PURITY MEASUREMENTS

The Division's development of new spectral-purity measurements supports sound specifications for aerospace systems such as radar systems and special communication systems. Systems capable of making highly accurate measurements of both phase-modulation (PM) and amplitude-modulation (AM) noise have been developed for carrier frequencies in the RF and microwave regions.[14] Portable systems have also been developed[15], and these are being used to validate measurements made in industrial and government laboratories. Further work will broaden the spectral coverage and simplify comparison of measurement accuracy among standards laboratories. New PM and AM calibration services have been brought into operation over the last several years.

SYNCHRONIZATION FOR TELECOMMUNICATIONS

The Time and Frequency Division has been actively engaged with the telecommunications industry in issues relating to synchronization of advanced generations of telecommunications networks. NIST has made useful contributions to emerging telecommunications systems, particularly in the area of phase noise measurement and the statistical measures used to characterize the noise in telecommunications synchronization systems. Over the last five years, the Division has offered annual workshops (jointly with industry) on synchronization in telecommunications systems.

TIME AND FREQUENCY BROADCAST SERVICES

The Division provides time and frequency broadcasts from stations WWV and WWVB in Fort Collins, Colorado, and from WWVH in Hawaii and a time code broadcast from NOAA's GOES weather satellites.[16] Last year, the Division initiated a project to increase the power output and reliability of the WWVB broadcasts at 60 kHz. At somewhat higher output power, these LF broadcasts could become substantially more useful for mobile and consumer applications, because the antenna/receiver cost and size would be very small and line of sight to the transmitter is not required. The Division also operates a Network Time Service and a telephone service, the Automated Computer Time Services (ACTS)[17], designed for setting clocks in digital systems.

These broadcasts serve applications in a broad range of systems in business, telecommunications, science, transportation, and radio/TV broadcasting. Industry calibration laboratories are served by the Division's Frequency Measurement Service, which provides these laboratories with continuous assurance of the accuracy of their frequency measurements.

APPLICATION OF TIME AND FREQUENCY TECHNOLOGY

Finally, the Division applies time and frequency technology to important problems in high-resolution spectroscopy[18] and quantum-limited measurements.[19]

DISCUSSION

We are witnessing a broad resurgence in the development of high performance time and frequency systems. This is the result of two key factors. First, satellite methods for time transfer now allow synchronization/syntonization of even the best atomic standards. Today's best standards simply could not be compared using the time transfer methods of the 1970s. The second factor involves the development of methods for controlling the states and motions of atoms using lasers. These new methods provide the means for circumventing the limitations inherent in the thermal-beam standards of the past. They make possible entirely new standards with a potential for reducing uncertainties by orders of magnitude.

Past advances in atomic timekeeping have opened up opportunities for advancing technologies requiring high-accuracy timing. Notable examples include satellite navigation, telecommunications, and electrical power distribution. If this history is any guide, we should expect similar technological advances to follow the development of the next generations of atomic standards. Program planning in the Time and Frequency Division of NIST is certainly based on that expectation.

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